REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE
Technical Papers

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
3058

5e. TASK NUMBER
RF9A

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

8. PERFORMING ORGANIZATION REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20030123 038

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Leilani Richardson
Unclassified	Unclassified	Unclassified	A		19b. TELEPHONE NUMBER *(include area code)* (661) 275-5015

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

21 separate items enclosed

NOTIFIED/FILE

3055PF9A

MEMORANDUM FOR PR (In-House Publication)

FROM: PROI (TI) (STINFO) 30 November 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-1999-0227**
Talley, D., "Overview of Pulse Detonation Engines" (BFI)

49th JANNAF Propulsion Meeting (Tucson, AZ, 14-16 Dec 1999) **(Statement A)**

BRIEFING FOR INDUSTRY
16 Dec 1999

Overview of Pulse Detonation Engines

Doug Talley
Air Force Research Laboratory|AFRL
AFRL/PRSA, 10 E. Saturn Blvd.
Edwards AFB, CA 93524-7660
(805)275-6174
Douglas.Talley@ple.af.mil

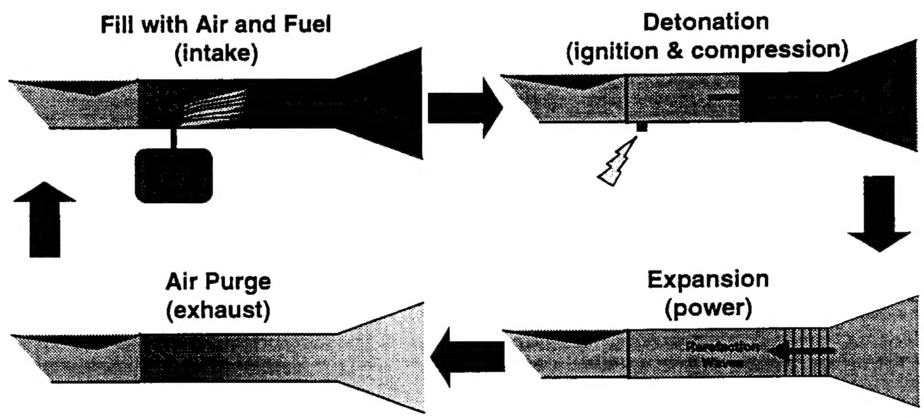
6.2 Objectives

Assess the technical merit of the pulsed detonation cycle and, if appropriate, develop pulsed detonation propulsion technology for Air Force applications.

	FY98	FY99	FY00	FY01
Funding ($1,000's)				
Edwards	810	309	309	309
WPAFB		731	298	298

Air Force Research Laboratory|AFRL

The Pulsed Detonation Cycle

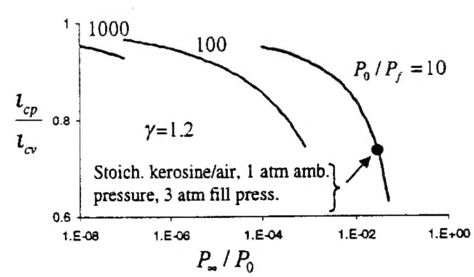


Air Force Research Laboratory|AFRL

The Potential

- Better Isp
- Higher thrust/weight (reduced feed pressures lead to lighter pumps)
- Deeply throttleable and scalable (multiple tubes, operating frequency)
- Lower cost / more reliable (less complex)
- Wider applicable Mach number range

Const. vol. estimate of Isp in comparison to a CP device operating at the same fill pressure (compares equivalent feed systems).



The Issues

- Ignition energy
- Deflagration-to-detonation transition (minimize DDT length)
- Practical fuels (JP, RP)
- Multiphase ignitions
- Oxygen enrichment
- Preignitions
- Themal loads
- Vibration and cycle fatigue
- Valves/injectors

Rocket - Specific Issues

- Filling in a vacuum
- Issues arising out of also having to inject an oxidizer
  - Different mixing regimes
  - Mixing and detonation of TWO condensed phases
- Different kinetic and rheological properties
  - Wide range of possible fuel/oxidants
  - Low/high temperature space environment
  - Lack of emphasis on emissions
- Higher rocket combustion temperatures
  - Hotter walls promote pre-detonation ?

Technical Approach

- Develop/use/oversee models of pulsed detonation processes
  - Ideal cases; limiting cases
  - Cycle decks
  - High fidelity models
- Experimentally assess the performance of in-house and proprietary pulsed detonation systems.
  - State of the art facilities
- Conduct in house *public domain* research and development
  - ITAR restrictions could apply

Strategic Alliances

Government

- NASA
  - Revcon
  - MSFC programs
- NAVY
  - MURI
  - 6.2
- SBIR funding

Industry

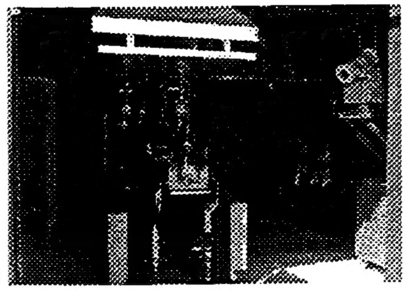
- APRI
- ASI
- Boeing
- Enigmatics
- GE
- HyPerComp
- Lockheed/Martin
- MSE
- RR/Allison
- SAIC
- UTRC/P&W

Academia

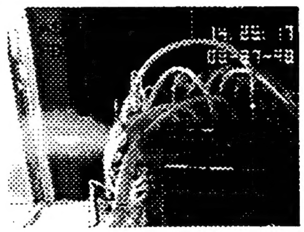
- Cal Tech
- NPS
- Penn State
- Princeton
- Stanford
- UCSD
- U. Forida
- U. Texas

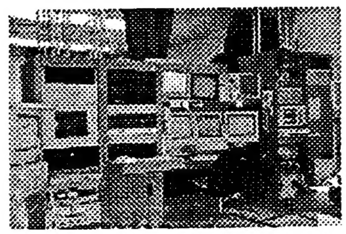
Hot fire facility for PDRE testing at Edwards AFB

Fuel	$H2(g)$, $CH4(g)$
Oxidizer	$O2(g)$
Purge gas	$N2(g)$, $He(g)$
H2 mass flow rate	.15 lbm/s (.07 Kg/s)
CH4 mass flow rate	.25 lbm/s (.11 Kg/s)
O2 mass flow rate	1.0 lbm/s (.45 Kg/s)
N2 mass flow rate	.5 lbm/s (.23 Kg/s)
Water flow rate	16 lbm/s (7 Kg/s)
Max. system press.	2640 psi. (179 atm)



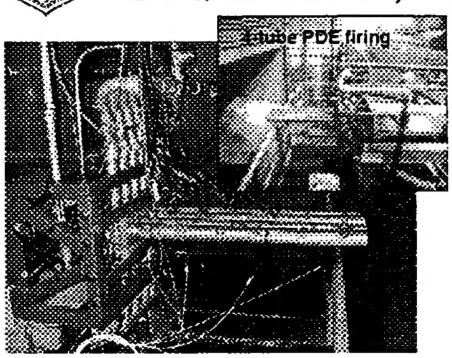
128 ch, 200 kbs scanning A/D
16 ch, 2 MHz per ch A/D, independently controlled
Central laser/optics room
Fully instrumented PDRE DAQ and control system





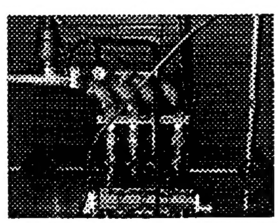
PDE Research Engine at WPAFB

GM Quad 4 DOHC, 4 Cylinder Pulsed Detonation Engine



- Junkyard Technology - $2,000 Hardware Investment
- Pontiac Grand Am Cylinder head (formerly 150 BHP) produces up to 3,000 lbf theoretical thrust as PDE
- Test-bed for PDE Research, Benchmarking
- Predetonator/Initiator Development
- High Frequency Operation
- Multi-tube EffectsPulsed Ejector Research

- Adapter Plate Mounts Detonation Tubes
  - 1-4 Tubes
  - 2" Diameter PDE Tubes for R&D
  - 3 1/2" Diameter PDE Tubes for Engine
- Electric Motor Driven Camshafts
  - 0.5-50 Hz currently (per tube)
  - 100 Hz possible
- Vapor Fuels: Hydrogen and Propane
- Liquid Fl: Gasoline, Ethanol, JP, etc.



Stock Intake Manifold with Ball Valve Selection of 1-4 Detonation Tubes

(Purge Manifold Similar)

FY99 Accomplishments

- Demonstrated contractor capability to build a back pressure with multiple tubes discharging into a common nozzle
  - Joint effort with Adroit Systems, Inc, and NASA
- Developed constant volume limit model
- Initiated study on the use of condensed phases in PDRE's, including monopropellants
- Initiated efforts to establish a panel to develop a community-standard PDE/RE performance methodology
- PRS-East accomplishments

— Air Force Research Laboratory|AFRL

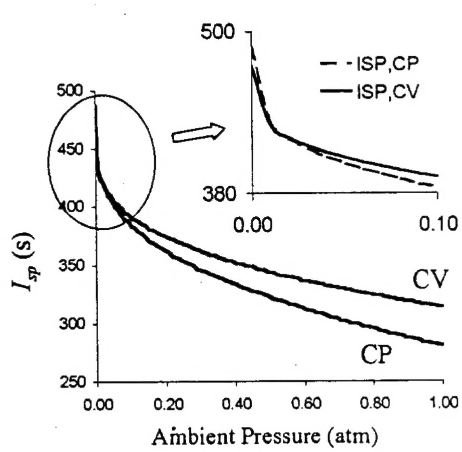
AFRL Constant Volume Code

Features

- Various propellants, variable mixture ratios
- Gaseous phase and liquid phase propellants
- Buffer gases and partial fills
- Nozzle options
  - Fixed area ratio nozzles
  - Area ratios continuously adjust to match pressure ratios during blowdown
  - Separated or non-separated flow
- Calculates Isp, average thrust, peak pressures, blow down times, area ratios, etc.

— Air Force Research Laboratory|AFRL

Effect of Ambient Pressure on Specific Impulse



GOX/GH2, MR=2.25
Complete expansion to ambient
5 atm fill pressure
Isentropic blow down

Theoretical result for expansion at infinite expansion ratio to a vacuum

$$\frac{I_{sp,CV}}{I_{sp,CP}} = \frac{2}{\gamma+1}\left(\frac{T_{CV}}{T_{CP}}\right)^{1/2} < 1$$

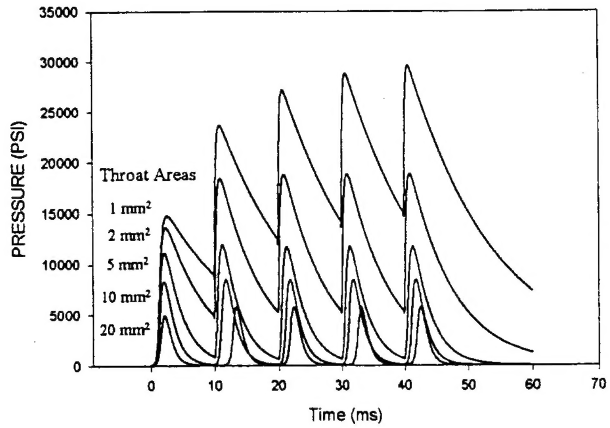
$$< (T_{CV}/T_{CP}) < \gamma$$

Placement of Symbols -

Air Force Research Laboratory|AFRL

Multi-cycle operation

$V_{chamber} = 10\ cm^3$ $V_{fuel} = 1\ cm^3$ frequency = 100 Hz

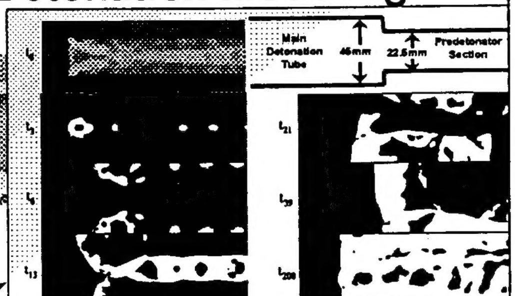


Combustion/Detonation Modeling

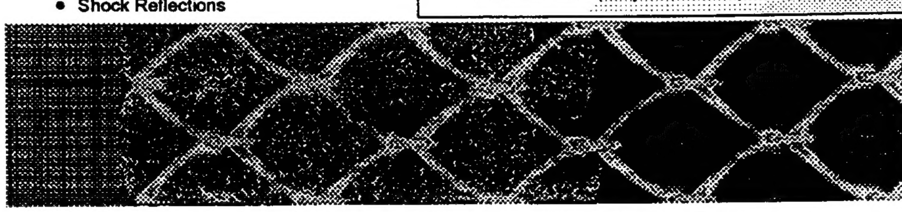
Dr. Vish Katta
(ISSI)
PRSC in-house contractor

AFRL/PRSC Detonation Modeling

- Currently one of two groups in the US modeling deflagration to detonation transition (DDT)
- Initiation and DDT Studies
- Detonation Propagation
- Confinement/Obstructions
- Shock Reflections



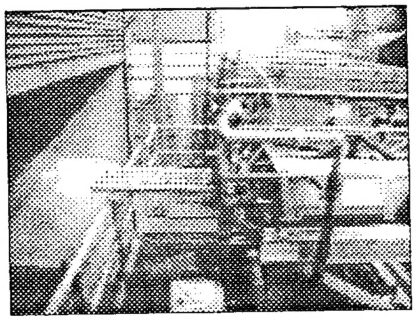
Detonation Propagation (direction is right to left)
Reflecting and coalescing transverse waves are the mechanism responsible for propagation of detonation from small tube (i.e. predetonator) to bigger tube



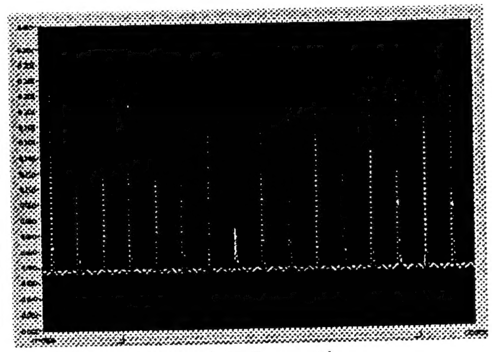
Peak Pressure or 'Smoke Foil' Traces with Particle Traces
(direction is right to left)

Successful Firing of 4-Tube AFRL Research PDE

Photo of firing



Pressure traces in a single tube



Signal (V) *vs* time

Air Force Research Laboratory|AFRL

Planned for FY00

- Facilitate JANNAF panel to oversee the development of a community standard PDE/RE performance model
- Demonstrate vacuum start of a multi-tube, common nozzle PDRE
  - Continuation of Adroit/NASA work
- Determine the feasibility of a "constant-volume combustion" pulsed engine operating on condensed phase propellants
  - Monopropellants and bipropellants
- PRS-East plans

Air Force Research Laboratory|AFRL

Videotapes

? Have these been approved?

Summary

something missing

- Significant facility upgrades have been installed at to support PDE/RE development and evaluation and demonstrated
  - PDRE development and firings at Edwards AFB
  - PDE development and firings at WPAFB
- Modeling efforts are underway in-house to support PDE/RE development
  - Constant volume code
  - Condensed phase code
  - DDT code
  - Other PRS-East codes
- AFRL is attempting to facilitate a panel to oversee the development of a community standard PDE/RE performance model